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**COMPARISON OF SEVEN SYSTEMS FOR
AIR CONDUCTION AUDIOMETRY FROM 8-20 KC/S**

Cecil K. Myers and J. Donald Harris

**Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF12.524.004-9010D.03**

Approved and Released by:

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COMMANDING OFFICER
Naval Submarine Medical Center**

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SUBMARINE MEDICAL RESEARCH LABORATORY
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SUMMARY PAGE

THE PROBLEM

To be able to measure human hearing acuity in a standardized manner in the region 8-20 kilocycles/second (kc/s).

FINDINGS

A test using the semi-automatic Békésy threshold-tracking procedure, and utilizing narrow bands of noise instead of pure tones, was created. Its test-retest reliability compared favorably with that of audiometry now standard in the frequency region of 0.5 — 8 kc/s.

APPLICATION

For medical and personnel specialists setting standards of hearing for sonar technicians or for other specialized listeners, and for otologists looking for early signs of damage to the ear from noise exposure, presbycusis, diabetes, or other disease or damage.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF12.524.004-9010D — Optimization of Auditory Performance in Submarines. The present report is No. 3 on this Work Unit. It was approved for publication on 18 February 1969 and designated as Submarine Medical Research Laboratory Report No. 567.

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ABSTRACT

Seven equipment systems were assembled to study human auditory acuity from 8-20 kilocycles/sec. Twenty-eight ears were examined. Two loudspeakers and two earphones were utilized, two types of stimulus (pure tones and narrow bands of noise, and two psychometric methods (Limits and Adjustments)). All systems were capable of providing usably reliable thresholds throughout the whole frequency range. When objectively calibrated, several systems (those involving loudspeakers, as well as those involving earphones), yielded quite comparable reference threshold sound pressure levels as inferred at the eardrum. A slight preference was expressed for a system, the method of using Békésy threshold-tracking, with a changing-frequency noise band 300 c/s in width, and for a discrete-tone system kindly loaned to us by Mr. Vincent Skee, which uses the Method of Constants.

COMPARISON OF SEVEN SYSTEMS FOR CONDUCTION AUDIOMETRY FROM 8-20 KC/S

Both theoretical and applied interest attaches to the upper frequency limits of hearing, and the problem of how to measure acuity accurately in these frequency regions has been worked over many times by a variety of persons, electrical engineers, otologists, and psychologists, among others. In modern (electronic) times, Fletcher¹ summarized four careful studies published by 1929, and offers a single graph relating a weighted average threshold in bars to frequency through 20 kilocycles per second (kc/s). The first commercial audiometer, the Western Electric 1A, provided at the earphone high frequencies, nominally of 8192, 10321, 13,004 and 16,384 c/s. An early Maico audiometer went up to 11,584 c/s, and even the Western Electric 2A still offered a frequency as high as 10 kc/s.

But although leading otologists of that day were impressed with the relevance of high-frequency audiometry for their clinical practice, it was quickly realized that problems of calibration and maintenance rendered these frequency regions difficult to control and use in any really standard fashion. Thus, for example, the American Medical Association Council on Physical Therapy in 1937 contented itself with specifying conditions for 8192 c/s, and this upper limit is still in use today. There are indeed those who claim that no audiological information exists in the audiogram at 8 kc/s which is not at least implicit at 6 kc/s, but the trend today is to extend rather than to restrict still further the limit of 8 kc/s.

A recent review² summarized several attempts with earphones of one sort or another to standardize minimum audible pressure (MAP) up to 20 kc/s for a young, normal-hearing population. A more recent study^{3, 4} examined 'normal' MAP up to 12 kc/s using earphones commonly found in the U.S.A., England, France, Germany and Japan.

Several aspects of these studies taken, in toto, render them less than fully satisfactory

as a base upon which a normative standard could at this time be erected. Consider, for example, the body of data upon which in 1964 the International Standards Organization promulgated a weighted average MAP through 8 kc/s: no less than 15 full-scale MAP studies from five different countries, with a subsequent massive effort to provide, by psychoacoustic loudness balancing, transfer information from one earphone type to another.⁵ But only a few absolute acuity studies have been carried out above 8 kc/s, and these with few subjects (Ss), or those not of an age or condition upon which audiometric standards should be based.

Furthermore, the specification of threshold sound pressure levels (SPLs) is fraught with difficulties. The only commercial high-frequency audiometer adopts as threshold, the SPL developed by the earphone tip in a free field, which the sealed ear canal distinctly is not. One MAP study² applied threshold voltage to the earphone coupled to an artificial head, the acoustic characteristics of which have not been published, but was certainly no exact replica of the human pinna, ear canal, etc. It is clear that the physical calibration of equipment for high-frequency audiometry is still far from agreed upon.

Something might be done to specify equivalent threshold SPL for MAP, if one had a transfer to MAP from thresholds obtained in a free field (minimum audible field, MAF). The specification of MAF is less ambiguous than MAP; it is only necessary to measure the threshold SPL in the free field at the point in space representing the virtual center of the subject's head during his threshold judgments. Three full-scale determinations of high-frequency MAF have been made, to 10 kc/s⁶, 15 kc/s⁷, and 23 kc/s⁸, but no study to date has established equivalent threshold SPL at MAP by collecting both MAP and MAF thresholds above 8 kc/s on the same Ss.

There is, finally, no correspondence as to the psychophysical methods used in high-

frequency studies—variations of the method of Constants, of Limits, and of Békésy-type tracking have all been used. None of these has provided any indication of the reliabilities of the observations.

One may summarize the situation by saying that no standardization of high-frequency audiometry is possible at the moment, because of differences among studies as to population, equipment, calibration procedures, and/or psychophysical method.

II. PURPOSE OF THE PRESENT STUDY

But, if valuable information is in fact contained in the sensitivity, or lack of it at the higher frequencies, it would seem incumbent on the profession of audiology to write standard specifications for testing hearing in these regions. This study is an attempt to take a few steps toward that goal:

(1) Several different audiometric systems were collected or constructed for the occasion, using different types of transducers, stimuli, and psychophysical procedure. Each system was used to collect thresholds twice at each frequency on well-motivated laboratory Ss. From the data, we hoped to determine whether MAP or MAF would be preferable for a clinical examination, what type of stimulus should be used, and what psychophysical method would yield best results.

(2) By providing threshold data on the same Ss (= loudness balancing at zero phon), we hoped to make possible direct comparisons of the data already in the literature among studies of high-frequency hearing. We hoped to use, as a reference base, threshold SPL for our most efficient system.

(3) By using ears which meet the usual specifications for audiometric standards, we hoped to provide one set of data which a standardizing body might later wish to use in its deliberations.

III. METHODS

1. Subjects.

Fourteen members of the laboratory staff were used. The first ten were 17-23 years of age, otologically normal, and met the usual requirements for an audiometer standards population.

2. Workspace.

The experimenter (E)* and all equipment, save a small intercom and the high-frequency transducer, were in a control space. The transducer and the S were in an audiometric chamber, a double-wall room of 13,392 ft³, lined with 30-in fiberglass wedges. S sat in a chair fitted with a chin rest used to fix his head so that for MAF measurements the ear was exactly 6 feet from the transducer. It was arranged so that the transducer looked directly into the test ear canal. Although the room was anechoic, the non-test ear was plugged for free-field tests.

3. Apparatus and Procedure.

a. **Noise-band MAF System:** A Brüel and Kjaer (B&K) 1024 noise generator set to a 300-c/s passband was centered on 7 kc/s and led to a Grason-Stadler (G-S) switch-timer combination set to a 1/3-sec on-off cycle. The signal was then led through a G-3 E3262A recording attenuator to a Sphericon loudspeaker.

In calibration procedures, voltage (V) to the loudspeakers was set to 2V at 10 kc/s, with the attenuator at 0. This created a moderately intense tone. Two methods of specifying SPL at S's head were used: (a) A Western Electric (W.E.) 640AA microphone was placed at a point 4-in above and 4-in back of the chin rest (this point was taken as the virtual center of S's head); and (b) the same microphone was inserted from the off side

*The assistance of James F. Willott, M.A., of Connecticut College, in collecting some of the thresholds in this report is gratefully acknowledged.

through the Shilling artificial head (for a photograph see Fig. 2 of reference 9), to occupy the position of the eardrum at the end of a 1-in canal of $\frac{1}{4}$ -in internal diameter. A blunt funnel mated the microphone to the canal.

Constant voltage of 2V was maintained in each case while the frequency was continuously swept from 8-20 kc/s. The output of the microphone (with associated Western Electroacoustic Laboratory power supply and SPL meter) was led to a B&K 2305 sound level recorder slaved to the noise generator. Paper records were thus provided of the absolute SPLs and frequency response of the system over a whole frequency range of interest, both at the virtual center of S's head and at the eardrum of an artificial head. Table 1 shows these data.*

In collecting thresholds, E seated S in the chair and presented the noise-bursts at some audible level at increasing frequency, watching the Békésy-type tracing which S was producing on the recording attenuator while tracking his threshold. It was necessary to be sure S had in fact reached his threshold by the time the generator had swept the 300-c/s band to a center frequency of 8 kc/s. A pen marked off frequency in 1- kc/s steps on the attenuator paper. The frequency was swept at a speed of 1 octave/8 min from 7-20 kc/s. Mid-tracing points were accepted as threshold.

b. Altec pure-tone MAF system: A General Radio (GR) 1304B oscillator, its frequency continuously monitored with a GR 1142-A meter, was connected to a G-S electronic switch and timer set to cycle the tone repetitively, $\frac{1}{3}$ -sec on, $\frac{1}{3}$ -sec off. The switch output was led to a Hewlett Packard (HP) 350 1-decibel (db) step attenuator, an Altec 1569A amplifier, and to an Altec 288C loudspeaker fitted with a cylindrical horn 7-in long, i.d. diameter $1\frac{1}{16}$ -in. Calibration was as with System (a) (see Table 1).

In collecting thresholds, E seated S, instructed him how to hold his head, estab-

lished intercom contact and presented a series of 8- kc/s tone spurts at some audible level, then further adjusted the attenuator in 5- and later 2-db steps using the Method of Limits with descending-ascending series until threshold had been crossed at least four times. The average setting for just-not-audible and just-audible was taken as the final threshold, rounded to the nearest db.

c. Skee Pure-Tone MAF System: A high-frequency audiometer made for the purpose was kindly loaned us by Mr. Vincent Skee, built upon the same principle as used in previous models by Dr. Samuel Rosen⁹. A pure-tone source with outputs as 10, 12, 14, 16, 18, and 20 kc/s was led through a manual interrupter circuit to a pair of Sphericon tweeters. The tweeters were mounted at one end of a 6-in open-sided cage; at the other end, a ring of softish material fitted around the entire pinna, touching the head firmly. Thus, the driver and the eardrum were rather more precisely and closely coupled than in the usual free-field study.

The attenuator dial on this audiometer, in 5-db steps, had been calibrated by Skee so that the "100" dial setting created 100 db SPL at a small microphone inserted at the entrance to a human ear canal. Therefore, a reading of, say, 75 db on the dial indicated an SPL of 75 db. However, in order to render the system more nearly comparable to the other systems used here, an additional calibration was performed. The driver cage was coupled to the Shilling artificial head and SPL read for the "100" attenuator setting (see Table 1).

In collecting thresholds, the same procedure was followed as for system (b) above, except that the pure tone was interrupted manually, and no less than 5 db steps could be used.

d. PDR-8 Pure-Tone MAP (Headband) System: The electronics of this system were identical to System (b) above, except that the earphone was fitted to the usual audiometric headband, with a force against the head of approximately 500 grams. The Method of Limits was used as in System (b)

* The assistance of Martin S. Harris, M.A., then of Connecticut College, in performing these calibration procedures is gratefully acknowledged.

TABLE I: Calibration Data

| System | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|----------------|-------|------|------|------|------|------|------|------|-------|-------|------|------|------|
| A ₁ | 92.5 | 94.5 | 96.0 | 97.0 | 97.0 | 95.0 | 94.0 | 94.5 | 88.0 | 84.0 | 86.0 | 88.0 | 87.0 |
| A ₂ | 92 | 82 | 96 | 100 | 105 | 105 | 100 | 88 | 86 | 84 | 89 | 90 | 86 |
| B ₁ | 101.5 | 100 | 98 | 94 | 99 | 93 | 85 | 74 | 86 | 87 | 85 | 75 | 79 |
| B ₂ | 86 | 79.5 | 77 | 77 | 83 | 88 | 68 | 62 | 53 | 59 | 64 | 62 | 55 |
| C | | 83.5 | | 87.5 | | 81 | | 71 | | 77.5 | | 75.5 | |
| D ₁ | 83 | 83 | 69 | 60 | 61 | 64 | 65.5 | 57 | 56 | 50 | 58.5 | 57 | 47.5 |
| D ₂ | 92.5 | 91.5 | 80.5 | 74.5 | 81 | 76 | 76 | 78 | 72 | 68.5 | 68.5 | 71 | 64 |
| E | 91 | 78.5 | 72.5 | 67 | 73 | 63.5 | 63 | 53 | 61.5 | 53.5 | 59 | 58.5 | 54.5 |
| F ₁ | 91.7 | 84.5 | 84.5 | 82 | 86 | 86.5 | 89.5 | 98 | 102.5 | - | 106 | - | - |
| F ₂ | 83.5 | 88 | 84 | 83 | 81 | 80.5 | 79 | 87.5 | 96 | 103.5 | - | - | - |

A₁: Noiseband MAF System; SPL measured at Virtual Center of S's HeadA₂: Noiseband MAF System; SPL measured in Shilling Artificial HeadB₁: Altec Pure-Tone MAF System; SPL measured at Virtual Center of S's HeadB₂: Altec Pure-Tone MAF System; SPL measured in Shilling Artificial Head

C: Skee Pure-Tone MAF System; SPL measured at Virtual Center of S's Head

D₁: PDR-8 Pure-Tone MAP System (Headband) System: SPL measured in Shilling Artificial HeadD₂: PDR-8 Pure-Tone MAP System (Handheld) System: SPL measured in Shilling Artificial HeadF₁: Rudmose MAP System; SPL measured in Shilling Artificial HeadF₂: Rudmose MAP System; SPL measured in free field

TABLE 11: Test-Retest Differences in Threshold Sound Pressure Level for All Systems

| System | | Kilocycles Per Second | | | | | | | | | | | | | | | | | |
|-------------------|-----|-----------------------|-----|-----|------|------|------|------|------|------|------|------|-----|----|--|--|--|--|------|
| | | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | | | | | |
| A: Mean | 3.9 | 4.0 | 3.2 | 3.5 | 3.6 | 3.3 | 4.4 | 5.4 | 5.2 | 4.6 | 3.6 | 3.1 | 4.9 | | | | | | |
| A: Standard Error | .86 | .58 | .42 | .63 | .62 | .18 | 1.02 | .89 | .95 | 1.0 | .77 | .86 | | | | | | | |
| N | 28 | 28 | 28 | 28 | 27 | 27 | 24 | 21 | 20 | 18 | 14 | 10 | | | | | | | |
| B: Mn. Dev. | 5.4 | 3.6 | 4.5 | 5.2 | 5.2 | 3.6 | 5.1 | 6.3 | 7.3 | 4.9 | 8.9 | 8.5 | | | | | | | |
| B: Standard Error | .12 | .50 | .71 | .94 | .94 | .74 | 1.03 | 1.22 | 1.14 | .98 | 2.71 | 4.47 | | | | | | | |
| N | 22 | 22 | 22 | 22 | 22 | 22 | 21 | 21 | 20 | 18 | 9 | 4 | | | | | | | |
| C: Mn. Dev. | | | | | | | | | | | | | | | | | | | 1.0 |
| C: St. Error | | | | | | | | | | | | | | | | | | | |
| N | | | | | | | | | | | | | | | | | | | |
| D: Mn. Dev. | 4.4 | 4.9 | 5.9 | 5.2 | 6.4 | 4.9 | 4.7 | 6.7 | 5.7 | 7.1 | 4.9 | 5.9 | | | | | | | 2.7 |
| D: St. Error | .65 | .78 | .76 | .81 | 1.00 | 1.07 | .92 | 1.4 | 1.56 | 1.66 | 1.61 | 2.16 | | | | | | | .52 |
| N | 28 | 28 | 28 | 28 | 27 | 27 | 26 | 21 | 17 | 9 | 7 | 6 | | | | | | | |
| E: Mn. Dev. | 4.5 | 5.7 | 4.0 | 5.5 | 4.4 | 4.7 | 7.1 | 6.2 | 6.8 | 8.1 | 9.3 | 9.1 | | | | | | | 6.7 |
| E: St. Error | .58 | .93 | .51 | .68 | .73 | .90 | .93 | 1.05 | 1.36 | 1.08 | 2.24 | 2.45 | | | | | | | |
| N | 28 | 28 | 28 | 28 | 27 | 27 | 26 | 25 | 20 | 15 | 9 | 7 | 4 | | | | | | |
| F: Mn. Dev. | 5.1 | 5.2 | 4.3 | 4.2 | 4.1 | 5.2 | 4.4 | 5.5 | 8.7 | | | | | | | | | | 8.7 |
| F: St. Error | .86 | .89 | .61 | .61 | .68 | .88 | .81 | .75 | 2.18 | | | | | | | | | | 2.43 |
| N | 28 | 28 | 28 | 28 | 28 | 26 | 23 | 22 | 21 | | | | | | | | | | |
| G: Mn. Dev. | 3.5 | 2.9 | 2.6 | 2.7 | 3.6 | 4.4 | 4.2 | 5.3 | 4.8 | | | | | | | | | | 5.9 |
| G: St. Error | .52 | .51 | .51 | .37 | .50 | .62 | .67 | .83 | .72 | | | | | | | | | | 1.01 |
| N | 26 | 26 | 26 | 26 | 25 | 23 | 21 | 20 | 20 | | | | | | | | | | |

Note: N = Number of Ears furnishing threshold

Note that the Reference System A was able to test about twice as many ears at 19 and 20 kc/s as any other system.

A:

Noise-band MAF System

B: Altec Pure-Tone MAF System

C: Ske Pure Tone MAF System

D: PDR-8 Pure Tone MAF (Headband) System

E: PDR-8 Pure-Tone MAF (Handheld) System

F: Rudmose MAF System (Handheld)

G: Rudmose MAF System (Headband)

TABLE III: Reference Threshold Sound Pressure Levels (RTSPLs) for the Reference Noiseband MAF System When Calibrated in a Free Field, and Comparisons in Decibels to yield Reference Equivalent Threshold Sound Pressure Levels (RETSPLs) for all Other Systems and Calibration Procedures.

| System | Frequency in Kilocycles Per Second | | | | | | | | | |
|----------------|------------------------------------|-------|-------|------|------|------|------|-------|-------|------|
| A_1 (RTSPL) | 17.3 | 28.5 | 23.0 | 22.2 | 25.4 | 29.4 | 27.9 | 37.6 | 37.8 | 40.4 |
| A_2 (RETSPL) | -0.5 | -12.5 | 0 | 3.0 | 8.0 | 10.0 | 6.0 | -6.5 | -2.0 | 0 |
| B_1 (RTSPL) | 11.2 | 5.5 | 10.6 | 8.8 | 7.3 | 6.5 | 15.2 | 9.9 | 18.4 | 19.2 |
| B_2 (RTSPL) | -4.3 | -15.0 | -10.4 | -8.2 | -8.7 | 1.5 | -1.8 | -2.1 | -14.6 | -8.8 |
| C (RETSPL) | | -4.6 | | | 3.0 | | 3.7 | | 1.0 | |
| D_1 (RETSPL) | -2.3 | 0.5 | 2.0 | -7.2 | -5.4 | 1.6 | 9.6 | -3.6 | -0.8 | 2.6 |
| D_2 (RETSPL) | 7.2 | 1.0 | 13.5 | 7.3 | 14.6 | 13.6 | 20.1 | 17.4 | 15.2 | 21.1 |
| E (RETSPL) | 5.7 | -5.0 | 4.5 | 0.8 | 6.6 | 1.1 | 2.1 | -10.6 | 6.7 | 4.1 |
| F_1 (RETSPL) | 7.7 | -11.3 | 1.4 | 4.1 | 6.6 | 6.0 | 11.8 | 10.7 | 17.5 | 20.2 |
| F_2 (RETSPL) | -0.5 | -7.8 | 0.9 | 5.1 | 1.6 | 0 | 1.3 | 0.2 | 11.0 | 17.7 |
| G_1 (RETSPL) | 5.7 | -13.6 | 1.2 | 1.8 | 5.1 | 0.4 | 9.0 | 10.4 | 18.8 | 22.6 |
| G_2 (RETSPL) | -2.5 | -10.1 | 0.7 | 2.8 | 0.1 | -5.6 | -1.5 | -0.1 | 12.3 | 20.1 |

A_1 : Reference Threshold SPL (RTSPL) for Reference Noiseband MAF System, calibrated in a free field

A_2 : Reference Equivalent Threshold SPL (RETSPL) for A_1 System, calibrated in Shilling Artificial Head

B_1 : RETSPL for Altec Pure-Tone MAF System, calibrated at virtual center of S 's head

B_2 : RETSPL for B_1 System, calibrated in Shilling Artificial Head

C : RETSPL for Skee Pure-Tone MAF System, calibrated in Shilling Artificial Head

D_1 : RETSPL for PDR-8 (Headband) MAP System, calibrated in Shilling Artificial Head

D_2 : RETSPL for D_1 System, calibrated in National Bureau of Standards Type 9A coupler

E : RETSPL for PDR-8 (Handheld) MAP System, calibrated in Shilling Artificial Head

F_1 : RETSPL for Rudmose (Handheld) MAP System, calibrated in Shilling Artificial Head

F_2 : RETSPL for F_1 System, calibrated in a free field

G_1 : RETSPL for Rudmose (Headband) MAP System, calibrated in Shilling Artificial Head

G_2 : RETSPL for G_1 System, calibrated in free field.

above. The notion here was to see what success could be achieved by using only the usual clinical audiometric apparatus and procedure, the oscillator circuit providing for frequencies above 8 kc/s.

Calibration was accomplished by coupling the headband-earphone unit (1) to the artificial head, and (2) to the National Bureau of Standards 9A coupler, with 0.2 V to the driver (see Table 1).

e. PDR-8 Pure-Tone MAP (Handheld) System: This system is exactly the same as preceding, except that S held the earphone as he chose. The listening technique was modelled after Harris and Ward², designed to reduce the critical importance of standing wave patterns, in the rigidly-held earphone system. E used the Method of Limits as in (b) above; S put the earphone on his knee after every judgment and moved it toward his ear only when told to do so by E; he was to listen at will, moving the earphone around, pressing it against his pinna, pulling it away, angling it, etc., to satisfy himself (and E by report) that he could or could not hear the tone spurts at that intensity.

In calibration, E likewise moved the earphone around the pinna of the artificial head, noting the highest SPL generated at the optimum position by the 0.2 V current (see Table 1).

f. Rudmose MAP System (Handheld): This is the TRACOR Co. Bekesy audiometer as arranged by Dr. Wayne Rudmose to provide tones of 8-18 kc/s in 1- kc/s steps, omitting 17 kc/s. An interrupted tone is on for 45 sec while S traces his threshold, then it automatically steps to the next higher frequency. The transducer is actually a high quality microphone, with a small cylindrical horn fitted with an olive to fit tightly into the ear. S holds the earphone firmly in the canal with one hand and tracks threshold with a switch held in the other hand.

In calibration, the audiometer was set to its maximum (nominally 80 db re audiometric zero), and the SPL measured in two ways:

(a) the transducer tip placed in a free field, looking into a W.E. 640AA micro-

phone (normal incidence) at a distance of 1/32 inch (this is the procedure used by Rudmose to calibrate this audiometry; for actual SPL at "0" on the audiometer card see Zislis and Fletcher¹⁰.)

(b) The transducer tip fitted snugly into the canal of the artificial head.

(c) These data are in Table 1.

g. Rudmose MAP System (Headband). Exactly as (f) above, except that a light headband locally constructed, with two small universal joints allowed E and S together to position the olive firmly and yet comfortably in the canal, where it remained untouched for the session. Of course, no additional calibration is needed.

4. Experimental Design.

The design and resulting statistics are of the simplest. Essentially, each S yielded threshold SPL at each frequency desired for each system, on each ear. These thresholds were then replicated in subsequent sessions on other days.

It was not convenient to counterbalance order of presentation of systems, which would have meant reassembling equipment several times per day. Generally speaking, all 28 ears were examined twice with each system before it was replaced by the next system. However, with these Ss and with the extended practice periods allowed for the relatively simple judgments demanded, we could not observe, nor do we feel there were, any systematic learning trends across systems. Our conclusions on this point are, however, rather poorly grounded.

IV. RESULTS AND DISCUSSION

1. Test-retest Reliability.

A first look at the consistency of the individual observation is provided by the average deviations of retest from test threshold SPL. For the seven systems these are in Table II, including a calculation of the standard error of that deviation.

a. Minimum Audible Field. Figure 1 shows the average deviation across frequency for the three MAF systems. Of the three MAF systems, the Altec Pure-Tone is definitely inferior. At all but one frequency the variance is less for both the other systems. On the other hand, there is little to choose between the Skee Pure-Tone and the Noise-band systems; at the four frequencies common to the two systems, and at which at least half of the S's could hear, the Skee system is superior in two, inferior in two, and in no case reliably so.

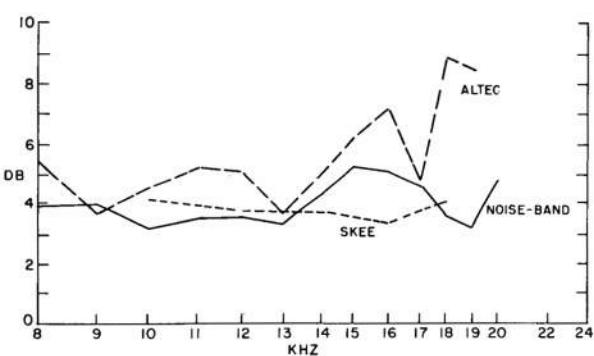


Fig. 1. Mean test-retest differences in db for three systems yielding minimum audible field, (MAF). Note: In this and all figures, abscissa is in kilocycles/second.

We note here that, for later standardization of MAF, either the Skee Pure-Tone or the Noise-band Systems can provide reference equivalent threshold SPLs with a test-retest consistency for the average individual Ss on the order of 5 db or less through 20 kc/s.

b. Minimum Audible Pressure. Figure 2 shows the average deviation across frequency for the four MAP systems. Of the four MAP systems, there was a distinct superiority in the TRACOR (Headband) System, at all frequency regions. Especially at 16-18 kc/s, the headband reduced the mean test-retest differences by 3-4 db, a highly reliable superiority. On the contrary, using a head-band with the PDR-8 earphone was no advantage, rather a disadvantage at 18 kc/s. Thus, the TRACOR (Headband) system incorporates an average variability of no great-

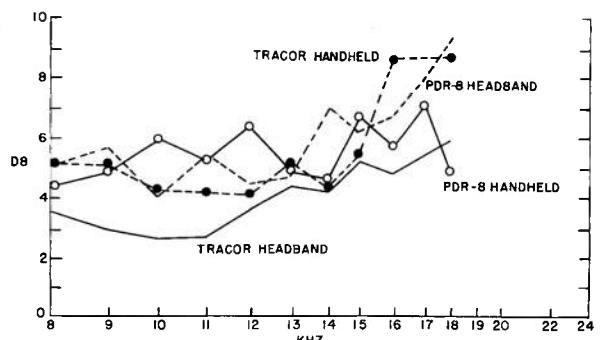


Fig. 2. Mean test-retest differences in db for four systems yielding minimum audible pressure (MAP).

er than 6 db, and even as small as 3 db, through 12 kc/s; while even the PDR-8 (Hand-held) system incorporates average individual variability of no greater than 5-7 db at any frequency.

We conclude thus far that the consistency of high-frequency audiometry through 20 kc/s need be only a few db worse than the consistency of 3-5 db often found, in studies too numerous to mention here, at the usual audiometric frequencies through 8 kc/s.

2. Loudness-Balancing among Systems; Reference Equivalent Threshold SPL.

For reference threshold SPL, we choose the data from the Noise-Band MAF system. In the first place, MAF is chosen rather than MAP because the calibration is less ambiguous. The Skee Pure-Tone System is not preferred, because only a few frequencies are available to define the audiometric curve. The Altec Pure-Tone MAF System is not preferred because of its larger variance.

In Table III, can be found the Reference Threshold SPL for the reference system and data from which the Reference Equivalent Threshold SPLs for each of the other systems can be calculated. Each line shows the SPLs, by frequencies, for one system compared to those from the Noise-band MAF reference system. It is more useful here to list

the differences between each system vs the reference system, rather than the actual threshold SPLs at each system because we are at the moment concerned not wth absolute values, but with how closely the threshold SPL from one system approximates that from another, the reference system. The absolute values for the R and L ears separately of our ten normal-hearing Ss are considered later.

Table III shows that the Altec Pure-Tone MAF System, when calibrated also in the free field (see Row B), yields Reference Equivalent Threshold SPLs generally 10-20 db louder than the reference system. This may mean that our Ss were that much better able to detect a narrow band of noise than a pure tone of equal SPL; some of this difference, though by no means all, would be predicted from the fact that the noise band of 300 c/s is smaller than the critical bandwidth of these frequency regions. On the other hand, the Skee MAF data (see Row C) agree with our Reference Threshold SPLs within usually much less than 10 db.

The MAP system of the usual audiometric PDR-8 earphone in a headband, when fitted to the NBS 9A coupler (see Row D₂) yields calibration data often 10 db more intense than when fitted to the Shilling Head (see Row D₁). However, when the optimum PDR-8 MAP (Hand-held) System threshold SPLs calibrated in the Shilling Head are examined (see Row E), they are seen to interweave very closely with the threshold SPLs of the reference system; data from the usual audiometric system thus can agree with the reference MAF system within usually 5 db or less.

The TRACOR (Headband) MAP System was stated earlier to be preferable to the Hand-held variant on the grounds of reliability; the divergence of its threshold SPL from Reference Threshold SPL (Rows G_{1,2}) is a bit subject to standing wave effects which are somewhat reduced using our free field calibration (G₂) instead of the Shilling Head. Except for three frequencies, the Threshold SPLs are, in fact, very close to the Reference Threshold SPLs of the reference

MAF system. At the higher frequencies (16+ kc/s), the maximum SPL yielded by the TRACOR System somewhat exceeds that of some of the other systems, and the same ears are not being compared here in all cases.

Figures 3-4 show some of these comparisons, the closest and the most divergent sets of thresholds for MAF and MAP respectively being compared to those of the reference system.

In Figure 3 it is seen that the Altec Pure-Tone MAF System does not at all comport with the reference MAF system when calibrated in the free field; neither does it do so when calibrated in the Shilling Head. However, the data for the Skee MAF SPLs, as calibrated in the Shilling Head, do interweave acceptably with the reference data.

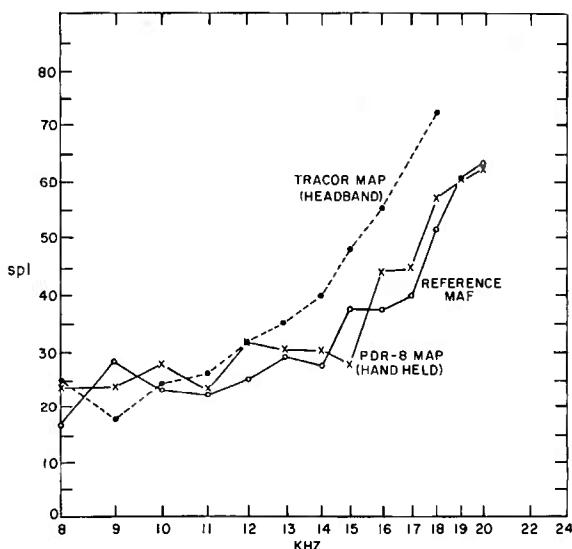


Fig. 3. Mean audiograms in sound pressure level re 0.0002 dyne/cm² for two MAF systems compared to the reference MAF system.

In Figure 3 it is seen that the thresholds of the reference Noise-band MAF system, and the PDR-8 Pure-Tone (Hand-held) MAP System, than which no two systems could be more unlike in stimulus, transducer, transducer-eardrum coupling, and psychophysical method, nevertheless yield data which interweave with what is usually a very small db difference.

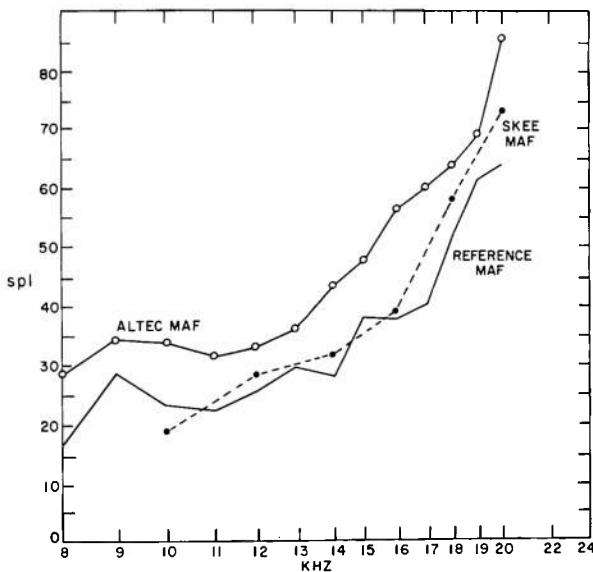


Fig. 4. Mean audiograms in sound pressure level (SPL) re 0.0002 dyne/cm² for two MAP systems compared to the reference MAF system.

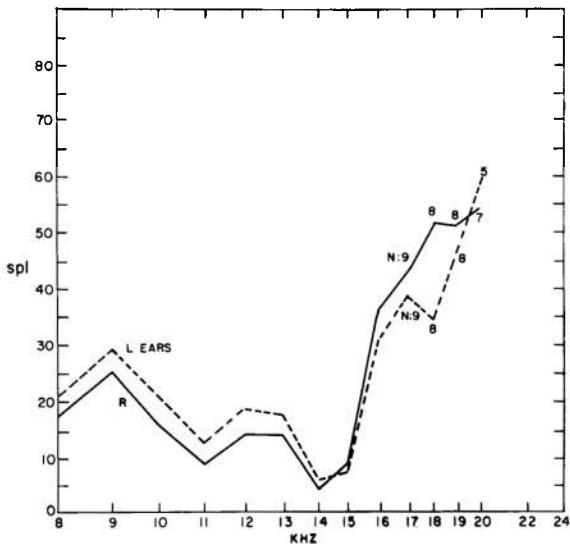


Fig. 5. Mean right and left ear audiograms for the reference MAF system.

3. Reference Threshold SPLs for Young Otologically Normal Ears.

This study cannot, of course, establish audiometric standards from 8-20 kc/s with only the few normal-hearing persons used here, but the data for the 10 such persons

within our population, nevertheless, has some relevance. Figure 5 shows the audiograms from our reference MAF system for these 20 ears. Data for the R and the L ears show no trends in favor of one ear over the other.

Figure 5 reveals the very remarkable fact that these ears did not really deteriorate in sensitivity until the frequency of 16 kc/s was reached. Evidently, the practice of depicting the human audiogram as a sharply deteriorating function above about 6 kc/s through 20 kc/s is not supported when a detailed look is afforded. Indeed, for young subjects (10-12 yrs)² (see Fig. 6), the deterioration is not marked even at 16-18 kc/s. Fig. 6 also shows the extensive (N:90 persons) binaural MAF data of Robinson and Dadson⁷, in which the threshold at 12 kc/s is no worse than at 8 kc/s, while even at 15 kc/s it is worse by

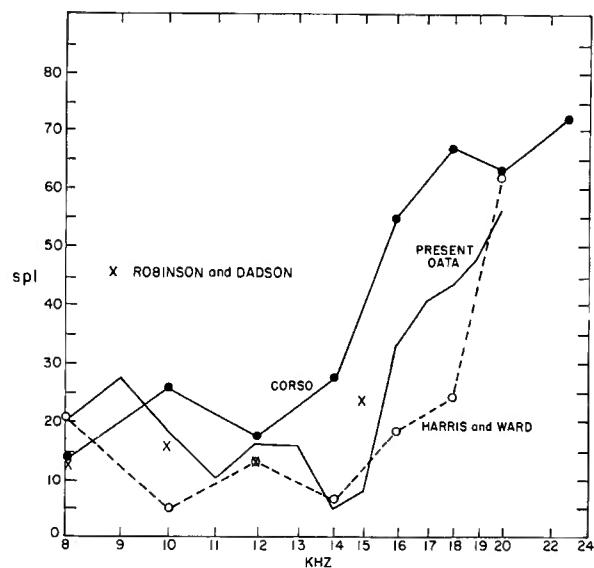


Fig. 6. Comparison of the mean audiogram (R and L ears combined); test-retest combined for the reference MAF system compared with three previous surveys.

only 10 db; and one must remember that their data was with S facing the loudspeaker directly, which would introduce a head-shadow correction factor in a way that would cause Robinson and Dadson's threshold data at 15 kc/s to be only a few db worse, if any, than at 12 kc/s.

The study most similar to ours is that of

Corso in 1965, briefly but perhaps adequately reported in 1967. MAF was measured on the R ears of 73 persons (data for men and women were not different, and were commingled). Figure 6 shows no special deterioration through 14 kc/s, though threshold at 16 and 18 kc were about 20 db worse than ours. Both studies agree that at somewhere around 15-16 kc/s, a sharp deterioration sets in up to 20 kc and beyond.

It is impossible without further Ss to state whether some or all of the irregularities in the data of Fig. 5 are due to real features in the hearing of our few Ss, or to undetected errors in calibration. We feel the former is more likely than the latter, in view of the satisfactory checks on our physical measurements with the Brüel and Kjaer 1/4-inch microphone.

Inasmuch as some of the divergences among high-frequency audiometry studies could arise from calibration problems, it seemed worthwhile to compare the performance of all systems using the one calibration method common to all, the Shilling artificial head. Fig. 7 shows that this standardization allows all systems to agree, within 5 db, usually throughout the whole range. The divergence of the TRACOR thresholds at 15+ kc/s has been discussed above.

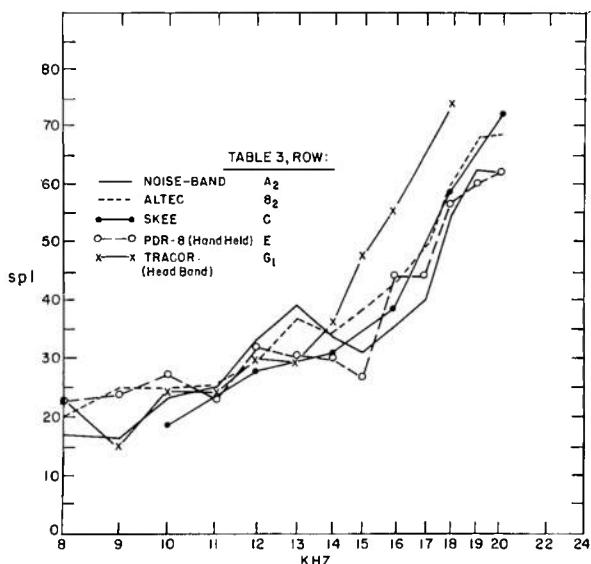


Fig. 7. Comparison of five systems all based upon the same calibration equipment and procedure.

V. SUMMARY AND CONCLUSIONS

In view of the importance of high-frequency hearing in many situations, a preliminary study was performed looking toward picking the most reliable and valid way to test absolute auditory acuity in the range 8-20 kc/s. Several systems were assembled to examine minimum audible field (loudspeaker), and minimum audible pressure (earphone). Each of seven systems and variants was used for test-retest on 28 ears of 14 persons under well-motivated and carefully standardized laboratory conditions. Calibrations were in a free field, in the NBS 9A coupler, or in the Shilling Artificial Head, as appropriate, using microphones with calibrations traceable to the National Bureau of Standards.

It was encouraging to find that all seven systems gave usable reliabilities, not much larger in fact than usually found for such data at 4-8 kc/s. There was, however, the possibility of preferring some systems over others on grounds of sensibly superior reliability.

Of loudspeaker systems, one generating pure tones over a 6-ft distance was distinctly inferior; two systems using a Sphericon "tweeter" loudspeaker were indistinguishable, one an instrument tailor-made by Mr. Vincent Skee using pure tones at 10, 12, 14, 16, 18, 20 kc/s, the other using a 300-c/s noise-band swept from 7-20 kc/s and utilizing Bekesy-type tracking. The latter for several reasons was named here the Reference System.

Of earphone systems, the TRACOR Co. high-frequency audiometer, with its high-fidelity earphone close-coupled to the ear canal, was superior, when it was affixed with a headband and universal-joint mounting. However, the usual audiometric PDR-8 earphone in MX cushion was inferior in reliability by only a few db, when a special psycho-physical procedure was used for threshold testing which reduced the effects of standing waves in the earphone-eardrum cavity coupling.

It is concluded that any of several systems can yield acceptably reliable high-frequency

audiometry through 20 kc/s, either by loudspeaker or by earphone. By earphone the best system examined was the TRACOR audiometer with the transducer fixed on the head; by loudspeaker, the best system was a pulsed 300-c/s band of noise automatically swept from 7-20 kc/s, the threshold obtained by Békésy-type tracking.

Examination of threshold SPLs by the latter system in a group of 10 young (17-23 yrs) otologically normal adults, revealed that the average audiogram for the R ears was very similar to that for the L ears, that no loss of sensitivity occurred until the frequency reached 16 kc/s, but that by the time 20 kc/s was reached only about half of the ears responded at the highest intensity used here. These results interweave with those of three previous studies of high-frequency acuity.

REFERENCES

1. Fletcher, H. *Speech and Hearing*. N.Y.: D. Van Nostrand, 1929.
2. Harris, J. D., and Ward, Mabel. High-frequency audiometry to 20 kc/s in children of age 10-12 years. *J. Audit. Res.*, 1967, 7, 241-252.
3. Delany, M. E. and Whittle, L. S. Reference equivalent threshold sound pressure levels for audiometry. *Acustica*, 18, 227-231, 1967.
4. Delany, M.E., Whittle, L. S., Cook, J. P., and Scott, V. Performance studies on a new artificial ear. *Acustica*, 18, 231-237, 1967.
5. Weissler, Pearl G. International standard reference zero for audiometers. *J. Acoust. Soc. Amer.*, 44, 264-275, 1967.
6. Churcher, G. B., and King, A. J. The performance of noise meters in terms of the primary standard. *J. Inst. Electr. Engr.*, 81, 57-90, 1937.
7. Robinson, D. W., and Dadson, R. S. A re-determination of the equal-loudness relations for pure tones. *Brit. J. Appl. Phys.*, 7, 166-181, 1956.
8. Corso, J. F. Air-conduction thresholds for high-frequency tones. *Eastern Psychol. Assoc.*, 1965, cited in: Corso, J. F. *The Experimental Psychology of Sensory Behavior*. N.Y.: Holt, Rhinehart and Winston, 1967.
9. Rosen, S., Plester, D., El-Mofty, A., and Rosen, Helen V. High frequency audiometry in presbycusis. *Arch. Otolaryngol.*, 79, 18-32, 1964.
10. Zislis, T., and Fletcher, J. L. Relation of high frequency threshold to age and sex. *J. Audit. Res.*, 6, 189-198, 1966.
11. Corso, J. F. *The Experimental Psychology of Sensory Behavior*. New York, N.Y.: Holt, 1967.

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13. ABSTRACT

Seven equipment systems were assembled to study human auditory acuity from 8-20 kilocycles/sec. Twenty-eight ears were examined. Two loudspeakers and two earphones were utilized, two types of stimulus (pure tones and narrow bands of noise, and two psychometric methods (Limits and Adjustments)). All systems were capable of providing usably reliable thresholds throughout the whole frequency range. When objectively calibrated, several systems (those involving loudspeakers, as well as those involving earphones), yielded quite comparable reference threshold sound pressure levels as inferred at the eardrum. A slight preference was expressed for a system, the method of using Bekesy threshold-tracking, with a changing-frequency noise band 300 c/s in width, and for a discrete-tone system kindly loaned to us by Mr. Vincent Skee, which uses the Method of Constants.

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